



Yan, TXJ., Nix, AR., & Hammuda, H. (1996). The effects of modulation and urban shielding on microcellular system capacity. In *Unknown* (Vol. 1, pp. 467 - 471). Institute of Electrical and Electronics Engineers (IEEE). <https://doi.org/10.1109/VETEC.1996.503491>

Peer reviewed version

Link to published version (if available):
[10.1109/VETEC.1996.503491](https://doi.org/10.1109/VETEC.1996.503491)

[Link to publication record in Explore Bristol Research](#)
PDF-document

University of Bristol - Explore Bristol Research

General rights

This document is made available in accordance with publisher policies. Please cite only the published version using the reference above. Full terms of use are available:
<http://www.bristol.ac.uk/red/research-policy/pure/user-guides/ebr-terms/>

The Effects of Modulation and Urban Shielding on Microcellular System Capacity

T X J Yan, A R Nix

Centre for communications Research
University Of Bristol
Queen's Building
University Walk
Bristol BS8 1TR, UK
Fax: ++44 (0)117 9255265
e-mail: t.yan@bristol.ac.uk

H Hammuda*

Department of Electronic and Electrical
Engineering
De Montford University
The Gateway
Leicester LE6 0YR, UK
Fax: ++44 (0116)2577052
e-mail: hmh@dmu.ac.uk

Abstract: *This paper evaluates the effects of modulation and urban shielding for modern microcellular systems. The capacity analysis makes use of the site specific ray-tracing propagation models previously developed at the University of Bristol.*

For a given microcellular location a site specific building database has been used to predict the signal coverage as a result of reflection, diffraction and scattering in the local environment. Taking into account a number of system parameters, such as modulation type, antenna pattern, SNR, C/I, and outage probability, the ray-traced propagation data has been extensively analysed to provide an accurate estimation of system capacity. Using this model, the impact of higher level modulation schemes such as 16-QAM is examined for microcellular networks.

I. INTRODUCTION

The effects of modulation and urban shielding on cellular system capacity has not draw much attention in the development of large cell systems. Several authors[1][2] have studied the impact of cellular network capacity in an interference limited system. These studies randomly located many users in a cell until the outage Cumulative Distribution Function (CDF) exceeded a required threshold. The propagation information was based on statistical models. However, unlike previous large cell scenarios, statistical models can no longer provide acceptable results in a microcell due to the site specific nature of the environment.

The concept of a microcell has been introduced into cellular networks to provide increased capacity within a limited radio spectrum allocation. Although microcells are not formally defined, they generally refer to small cells (<1km) in an urban area where the base station antennas are significantly lower than the surrounding roof tops. Therefore, unlike conventional large cell scenarios, where base station antennas are often placed on the tallest building, a microcells' coverage area is largely governed by the effects of surrounding buildings (urban shielding). Microcells may operate using lower transmit power

at the base station, and this will further reduce the coverage area. The lower transmit power, combined with the effects of urban shielding, results in a shorter reuse distance, hence cell frequencies can be reused more often in a given area. A high density of reuse cells will naturally increase system capacity.

For microcellular studies, the propagation models should take into account the exact position of each individual building. Therefore, in a cochannel interference limited environment, the capacity can be deterministically evaluated by studying the effective coverage area of each individual cell. The propagation coverage for each cell site can be obtained by using deterministic ray-tracing techniques. Thus the developed capacity evaluation model will enable system designers to consider the impact of shielding and shadowing effects in the planning of future microcellular networks.

II. CAPACITY EVALUATION MODEL

In a cochannel interference limited cellular system, each cell is surrounded by many reuse cells. There are six reuse cells in the first tier and twelve reuse cells in the second tier, this is true regardless of the reuse pattern. The first tier of reuse cells are the major source of cochannel interference[7]. In practice, all cochannel cells in urban areas show very similar characteristics in terms of signal variation versus coverage area. Therefore, an average signal behaviour for the cochannel cells can be derived. When system BER & system outage probabilities are applied, an average reuse distance can be obtained for the type of environment being considered. This enables the capacity to be accurately estimated in terms of channels/MHz/km².

To further explain this method of capacity evaluation, two essential modelling processes will be presented, namely radio propagation coverage prediction and capacity assessment.

The proposed propagation method for obtaining our coverage predictions has been developed by Athanasiadou, Nix and McGeehan[3] and is based on the concept of ray-tracing. The model assumes that walls in each microcell are infinitely tall, this assumption is normally valid since microcells have base

*Currently with De Montfort University

stations and mobiles below the roof top. Walls are assumed to be perpendicular to the ground but not necessarily to each other, the ground is flat. These limitations are acceptable for most urban microcellular environments.

Each wall is characterised by its permittivity, conductivity, and thickness. Wall thickness is required in the calculation of the reflected and transmitted field strength. The reflection and transmission coefficients are evaluated as a function of incident angle for a range of different wall materials. The equations used to calculate the received signal energy have been presented by [3][4][5] as:

$$P_r = \frac{P_t G_t G_r \lambda^2}{(4\pi)^2 d^2} \left[\prod_j R_j \right] \left[\prod_l T_l \right] \left[\prod_k A_k(s', s) D_k \right]^2$$

where P_t represents the transmitter power, d is the total length of the ray path, λ is the wavelength, G_t and G_r are the transmitting and receiving antenna gains in the direction of each ray, R_j is the angle dependent reflection coefficient for the j^{th} path, T_l is the angle dependent wall transmission coefficient for the l^{th} transmission and D_k the diffraction coefficient for the k^{th} diffracting wedge. The diffraction coefficients are also multiplied by a spatial attenuation function $A_k(s', s)$ which finds the correct multiplicative diffraction coefficient given the $1/d^2$ dependence in the first term.

In a cochannel interference limited mobile radio system, adequate signal strength and signal to interference ratios (SIR) are essential for successful communications. Outage probability, defined as the probability of failing to simultaneously achieve a signal to noise ratio (SNR) and a signal to interference ratio sufficient to give satisfactory reception, is an appropriate measure for evaluating the performance of mobile radio systems[6].

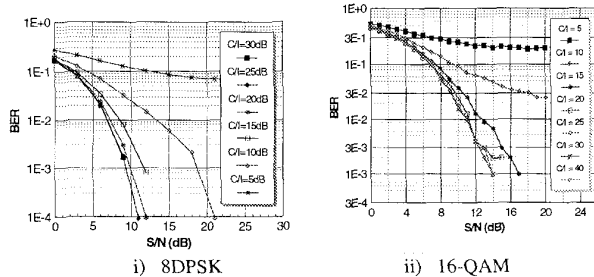


Fig.1 BER v S/N In the presence of Cochannel Interference

Fig.1 shows the result of a system simulation using differential 8DPSK and coherent 16_QAM. In the presence of cochannel interference and AWGN noise, it clearly shows that for a required BER and a required cochannel interference ratio, the signal to noise ratio can be determined. If the transmit power is reduced, a higher cochannel interference ratio must be used to achieve the required system BER. These parameters are generally considered as fundamental factors in mobile radio system design and will be used in the subsequent capacity evaluation.

III. MICROCELL STRUCTURE EVALUATION

The system reuse distance is referred to as the average reuse distance in a microcellular network where the same frequency channels are in use. Naturally, in microcellular network planning, when the channel occupancy and teletraffic density are uniform, more reuse cells equate to a higher capacity. Therefore, the accurate prediction of the average reuse distance can result in an enhanced and more cost effective cellular design.

The method for evaluating the system average reuse distance is divided into two steps. The first step assumes the system is noise limited and cochannel interference is ignored. Cell signal coverage for a given transmit power can be obtained using the ray tracing model described earlier.

The average cell radii is defined as the distance from the base site, within which the required Signal to Noise ratio and outage probability are maintained.

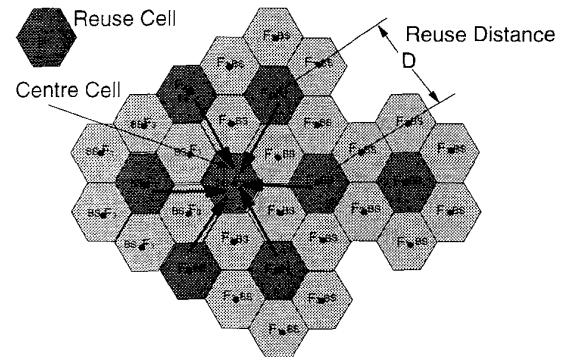


Fig.2 Cochannel Interference Contribution

When cochannel cells exist, the system becomes interference limited. The minimum distance which allows the same frequency to be reused will depend on many factors, such as the number of cochannel cells in the vicinity of the centre cell, the type of geographic terrain, the antenna height, antennas pattern and transmission power at each base site. In this paper, the technique presented for evaluating the minimum reuse distance makes use of all these parameters.

Fig.2 shows a three cell reuse pattern, where each cochannel cell is highlighted. The first tier consists of six cochannel cells. It is practical to assume that the cochannel interference is mainly contributed by the first tier of cochannel cells[7]. This allows the cochannel interference to be modelled as the total contribution of six cochannel cells.

The study shows that in the same urban environment, the signal path loss shows very similar characteristics in each cell. Thus the cochannel pathloss characteristics of each interferer can be duplicated from the statistics of the centre cell. Fig 3 shows the situation with cochannel interference. This result is taken from a statistical propagation model. With reference to the required signal to interference ratio and outage probability, the six cochannel cells can be moved towards the centre cell as shown

in Fig 3. This diagram shows the received signal level in contrast to the received cochannel interference level as the cochannel cells are moved towards the centre cell. In this process, the defined signal to interference ratio and outage probability will eventually be satisfied at a point corresponding to the minimum reuse distance.

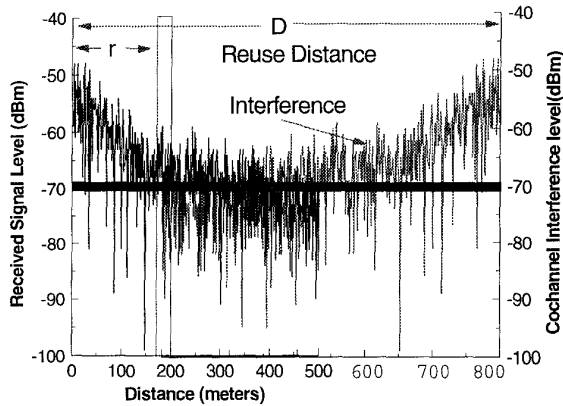


Fig.3 Determination Of Average Reuse Distance

The evaluated minimum reuse distance can be regarded as an average reuse distance of a defined cluster area. With the evaluated average system radii from the previous section, it is now possible to calculate the capacity of the microcellular system.

IV. CAPACITY ASSESSMENT TECHNIQUES

The microcellular system capacity can be described using Erlangs per Km^2 , so long as each cell traffic condition and channel allocation are defined. The spectral efficiency of the system is defined as [7]

$$\eta_s = \frac{\text{Total number of channels available}}{\text{Total BW available} \times \text{cluster area}}$$

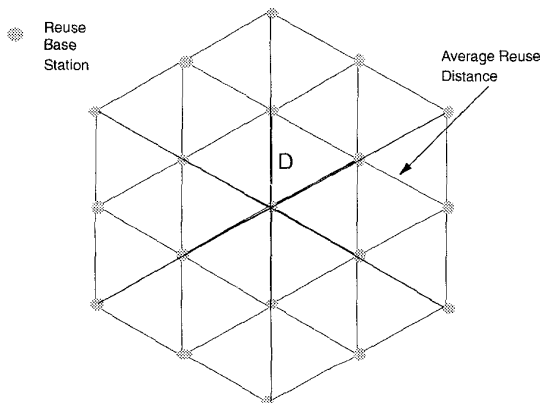


Fig. 4 Optimum Reuse cell Pattern in a Cluster area

thus the spectral efficiency can be expressed as *Channels per MHz per kilometre squared*. Therefore, to calculate the spectral efficiency, the cell planning pattern must be identified in a cluster area. Taking results from the previous sections, the reuse cell pattern can be planned, as shown in Fig 4. The cluster size k is derived using Lee's [7] equation $k = D^2 / 3r^2$, where D represents reuse distance and r the cell radius.

Fig 4 shows that the optimum reuse pattern can now be planned in a given area. This concept can be used as a realistic approach for planning the reuse pattern in microcellular networks. Because the average cell radii is a known factor, the total number of cells allowed in a cluster area can be derived.

V. CASE STUDY RESULTS

Using the described microcellular capacity estimating model, a study has been implemented based on the building database for a typical UK urban environment. The 500x500 meter area shown in the map includes many buildings of various materials and heights.

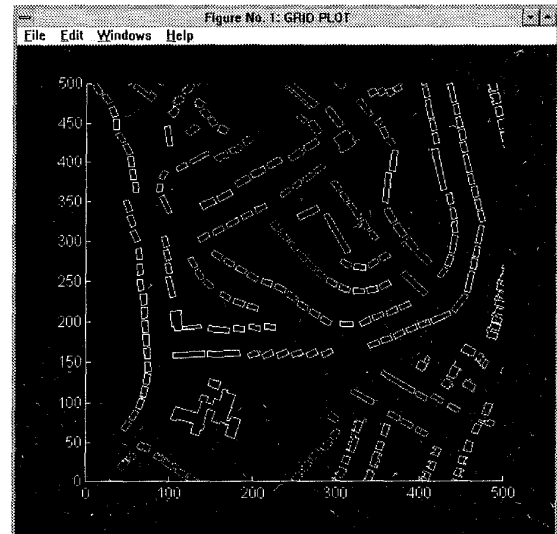


Fig.5 Map of the Test Area

To study the area coverage, a base station was placed at $x=225\text{m}$, $y=305\text{m}$. The antenna height was 10 meters and the pattern was based on a vertical dipole. Using the ray model described earlier, the signal coverage of the area can be obtained as shown in Fig.6. In this particular study, the simulation parameters are summarised as:

• Input system parameters

- 1) Modulation Schemes: 8DPSK, 16_QAM
- 2) BER requirement: See Fig.1
- 3) Outage probability: 10%
- 4) Frequency Band: 1800MHz, 900MHz
- 5) Transmission power: +40dBm
- 6) Antenna Height: 10m
- 7) Antenna Gain: +2.4dBi

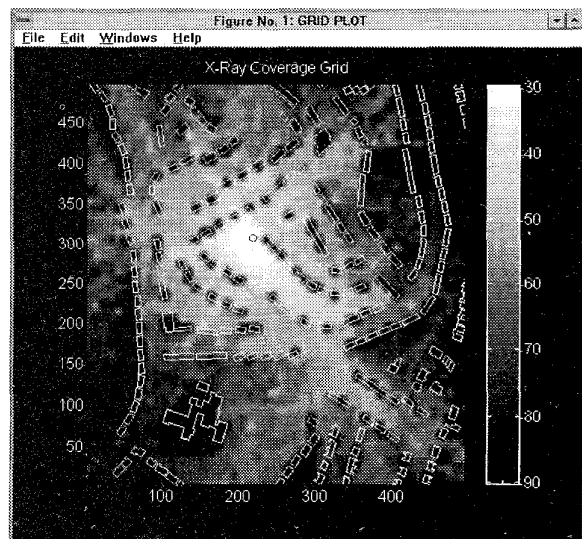


Fig.6 Signal level in Grid Map

The grid display map clearly shows the shape of the coverage and the received signal level around the buildings. From the obtained grid study, the average signal propagation pathloss is derived as a function of distance. Fig.7 shows the average statistical propagation path loss in all directions around the base station as the mobile moves away from the base site.

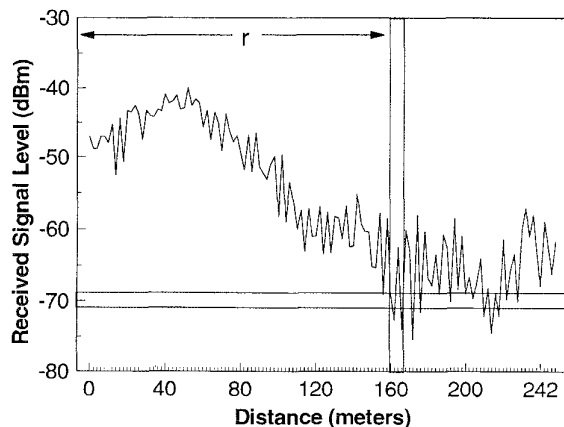


Fig.7 Average Street Propagation Pathloss (1800MHz)

When the minimum received signal level is set at -70dBm and a coverage probability of 90% is required, the evaluated average cell radius is 160m as shown in Fig.7. The noise considered is Additive White Gaussian Noise.

Another essential estimation parameter is average reuse distance. Using the previously described method shown in Fig.3, the evaluated average reuse distance is 600m. Thus a second set of parameters can be listed.

• Evaluated Parameters

	1800MHz	900MHz
1) Average cell radius:	160m	250m
2) Average reuse distance:	600m	1200m

3) Mobile receiver height:	1.5m	1.5m
4) Mobile antenna Pattern:	Omni	Omni
5) Cluster Size $k = D^2/3r^2$	4.68	7.68

In comparison to the capacity assessment model developed by [1], this method greatly reduces the number of assumptions that has to be made, instead the most important parameters are produced by propagation analysis. The technique also takes into account the effect of modulation and carrier frequency. This allows the suitability of higher level modulation schemes and higher carrier frequencies to be investigated in a microcellular network.

Propagation pathloss data obtained from a ray tracing model can provide useful information about a particular site. Fig.8 shows that for this site, 16_QAM modulation has a clear advantage over 8DPSK due to the fact that for a specified Bit Error Rate requirement, 16_QAM can tolerate a higher level of cochannel interference as shown in Fig.1, this allows the average reuse distance to be reduced. It is also shown that urban shielding has significant impact on restricting the cell size, in comparison with free space transmission.

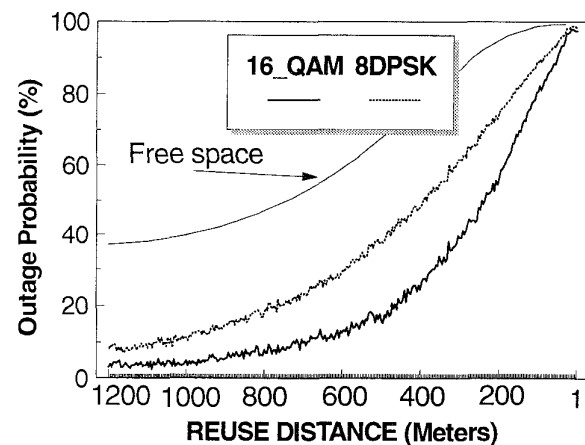


Fig.8 Simulated Result of Cochannel Interference Outage Probability (1800MHz)

Often transmission power can be adjusted to control the cell radii in a microcellular system. The following diagram is a statistical simulation result showing the relationship between the cell radii and transmission power. When the system parameters are set at those mentioned previously, it is quite clear that lower transmission powers can reduce cell radii, it is also interesting to note in the diagram that the achieved cell radii between the two frequency bands (900MHz, 1800MHz) can be small when the transmission power is reduced to a low level.

Employing the 1800MHz frequency band has a clear advantage in reducing the reuse distance for a given cochannel interference level. Fig.10 shows a numerical relationship between the cochannel outage probability and the carrier to interference ratio.

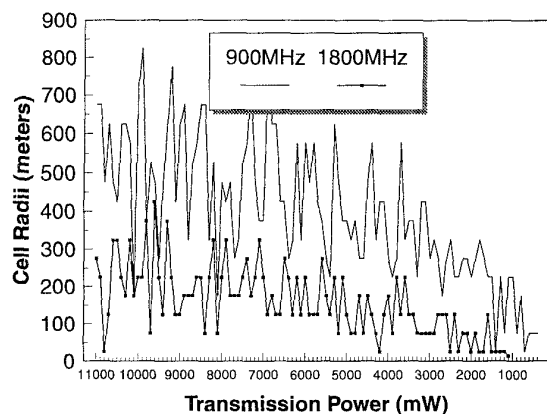


Fig.9 Transmission Power Control on Cell Radii in a Microcellular environment

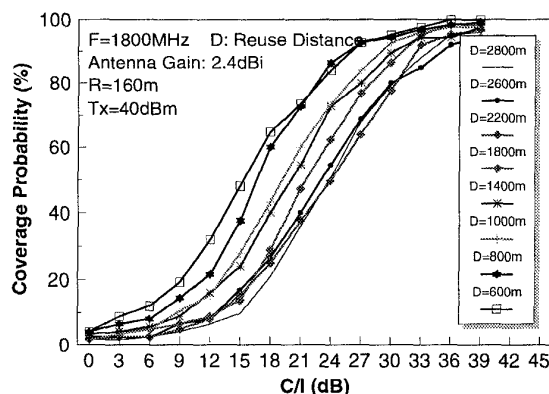


Fig.10 Trade off between Carrier to Interference Ratio and the Reuse Distance

Obviously, the larger the reuse distance, the lower the carrier to interference required to achieve the same cochannel outage probability. The simulated carrier frequency is 1800MHz, the transmission power is 40dBm and the antenna gain is +2.4dBi.

VI. CONCLUSIONS

A detailed study of a typical UK urban area using the developed capacity assessment method for microcellular systems has been presented in this paper. Paper [8] provides a detailed description of the model. The model is based on a deterministic propagation model in a particular microcellular environment. The intention is to reduce the number of assumptions so that a more accurate system capacity estimate can be achieved. In practice, the output data would be averaged over a number of possible base-station locations.

There are many factors that limit system capacity. This paper has investigated the effects of urban shielding and modulation and shown how they impact on average cell radii, reuse distance and capacity.

ACKNOWLEDGEMENTS

Timothy Yan wishes to thank De Montfort University (UK) for their financial support. The authors would also like to acknowledge Georgia Athanasiadou for her helpful discussions regarding ray tracing and microcellular modelling. Finally, the authors are grateful for the use of the University of Bristol's X-Ray propagation software.

REFERENCES

- [1] J M Short, B Zako, "A Capacity Estimation Model For Cellular System", IEEE Proc. On Personal, Indoor and Mobile Radio Communication, King's College, London, September 1991.
- [2] R Prasad, A Kegel, "Performance Analysis of A Digital Mobile Radio Cellular System In Presence Of Cochannel Interference, Thermal and Impulsive Noise", IEEE Proc. On Personal, Indoor and mobile Radio Communication, King's College, London, September 1991.
- [3] G E Athanasiadou, A Nix, J P McGeehan, "A Ray Tracing Algorithm for Microcellular Wideband Propagation Modelling", Accepted by Vehicular Transaction Conference 1995.
- [4] H R Anderson, "A Ray Tracing Propagation Model for Digital Broadcast Systems In Urban Area", IEEE Trans. on Broadcasting, Vol.39, no 3, September 1993.
- [5] K R Schaubach, N J Davis IV, "Microcellular Radio Channel Propagation Prediction", IEEE Antennas and Propagation Mag, pp25-34, August 1994.
- [6] Y D Yao, A U H Sheikh, "Outage Probability Analysis For Microcell Mobile Radio Systems With Cochannel Interferences In Rician/Rayleigh Fading Environment", Electronics Letters, Vol.26, No.13, 21st June 1990
- [7] W C Y Lee, "Mobile Cellular Telecommunication System", ISBN 0-07-100790-3, 1990
- [8] T Yan, A Nix, H Hammuda, "A New Method of Evaluating Microcellular System Capacity", Globecom Conference, November 1995, Singapore.